AD/A-001 099

OBSERVED RAYLEIGH WAVE GROUP VELOCITIES AND SPECTRAL AMPLITUDES FOR SOME EURASIAN PATHS

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Texas Instruments, Incorporated

Prepared for:

Advanced Research Projects Agency
Air Force Technical Applications Center

28 February 1974

ALEX(01)-TR-74-01

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TECHNICAL REPORT NO. 1

VELA NETWORK EVALUATION AND AUTOMATIC PROCESSING RESEARCH

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TEXAS INSTRUMENTS INCORPORATED
Equipment Group
Post Office Box 6015
Dallas, Texas 75222

Contract No. F08606-74-C-0033
Amount of Contract: $402,489
Beginning 1 November 1973
Ending 31 October 1974

Prepared for

AIR FORCE TECHNICAL APPLICATIONS CENTER
Alexandria, Virginia 22314

Sponsored by

ADVANCED RESEARCH PROJECTS AGENCY
Nuclear Monitoring Research Office
ARPA Program Code No. 4F10
ARPA Order No. 2551

28 February 1974

Acknowledgment: This research was supported by the Advanced Research Projects Agency, Nuclear Monitoring Research Office, under Project VELA-UNIFORM, and accomplished under the technical direction of the Air Force Technical Applications Center under Contract No. F08606-74-C-0033.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER
AD/A-001 099

4. TITLE (and Subtitle)
OBSERVED RAYLEIGH WAVE GROUP VELOCITIES AND SPECTRAL AMPLITUDES FOR SOME EURASIAN PATHS

5. TYPE OF REPORT & PERIOD COVERED
Technical

6. PERFORMING ORG. REPORT NUMBER
ALEX(01)-TR-74-01

7. AUTHOR(s)
David G. Lambert

8. CONTRACT OR GRANT NUMBER(s)
F08606-74-C-0033

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Texas Instruments Incorporated
Equipment Group
Dallas, Texas 75222

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
VELA T/4705/B/ETR

11. CONTROLLING OFFICE NAME AND ADDRESS
Advanced Research Projects Agency
Nuclear Monitoring Research Office
Arlington, Virginia 22209

12. REPORT DATE
28 February 1974

13. NUMBER OF PAGES
29

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
Air Force Technical Applications Center
VELA Seismological Center
Alexandria, Virginia 22314

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

ARPA Order No. 2551

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Eurasian Group Velocities
Eurasian Group Spectra
Very Long Period Experiment (VLPE)
Technical Report No. 1

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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Fundamental Rayleigh wave group velocities and spectra were determined using narrowband filters to minimize possible multipath and higher mode effects. Further, the spectra were corrected for geometrical spreading and effective attenuation.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

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20. continued

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ABSTRACT

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Fundamental Rayleigh wave group velocities and spectra were determined using narrowband filters to minimize possible multipath and higher mode effects. Further, the spectra were corrected for geometrical spreading and effective attenuation.

Observed Rayleigh wave group velocities for propagating paths crossing Central India, and the Russian and Siberian platforms were in close agreement to those observed for the Central United States. The observed group velocities and amplitude spectra for paths in and normal to the Alpine-Himalayan Fold System indicate the presence of thick crustal sections having high effective attenuation properties.

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SECTION I

INTRODUCTION

The establishment of the Very Long Period Experiment (VLPE) provided a small network of high gain, high quality, long-period digital seismographs at various locations throughout the world. Further, the availability of a list of confirmed and well located events occurring during the International Seismological Month (ISM) provided the opportunity to determine and compare Rayleigh wave group velocities of several continental travel paths in Eurasia to those determined by others.

For this study, we selected three central Asian events which occurred during the ISM and were recorded at several VLPE stations located in Eurasia. Fundamental Rayleigh wave group velocities and spectra were determined using narrowband filters to minimize possible noise, multipath, and high mode effects.

The spectra were corrected for geometrical spreading and effective attenuation. Turnbull, et al. (1973) using Tryggvason's method (1965) determined the effective attenuation for a selected path from Sinkiang to Chang Mai, Thailand (CHG).

The group velocities are compared to those determined by Santô and Satô (1966) for various tectonic regions in Eurasia and to those determined by Brune and Dorman (1963) and McEvilly (1964) for the mid-continental United States.

These data provide the basis of the discussion for our spectral estimates and group velocities.

SECTION II

DATA AND METHOD OF ANALYSIS

A. DATA USED

Seismic recordings from the VLPE stations at Chiang Mai, Thailand (CHG), Fairbanks, Alaska (FBK), Toledo, Spain (TLO) and Kongsberg, Norway (KCN) were selected for three earthquakes located near the USSR-Mongolia border, in Tadzhik, and southwestern Afghanistan. Event and station parameters are given in Table I. From these twelve station-event combinations we have long-period data for ten of the possible Eurasian paths. No record was available at TLO for event 231 and the signal to noise ratio was too small for any type of signal analysis of the record at FBK for event 392. Station and event locations along with the great circle path representations are shown in Figure II-1.

B. METHOD OF ANALYSIS

The determination of fundamental mode Rayleigh wave group velocities and amplitude spectra was accomplished with the use of a series of narrow band filters. Briefly, for this analysis we filter in the frequency domain with a series of narrow band filters with specified center frequencies. The center frequencies selected correspond to periods of 15 through 60 seconds at 5 second increments (i.e. T = 15, 20, 25, . . .etc.). The inverse Fourier transforms of these computations result in series of time traces having well behaved oscillating functions. The specifics of the method are given by Alexander (1963), Archambeau et al (1965), and recently by Turnbull et al (1973). The resultant oscillating wave packets correspond to group energy packets with the largest peak amplitude generally corresponding both in time and amplitude to the dominant mode. Figure II-2 is a typical example of the application of narrow band filtering.

TABLE II-1

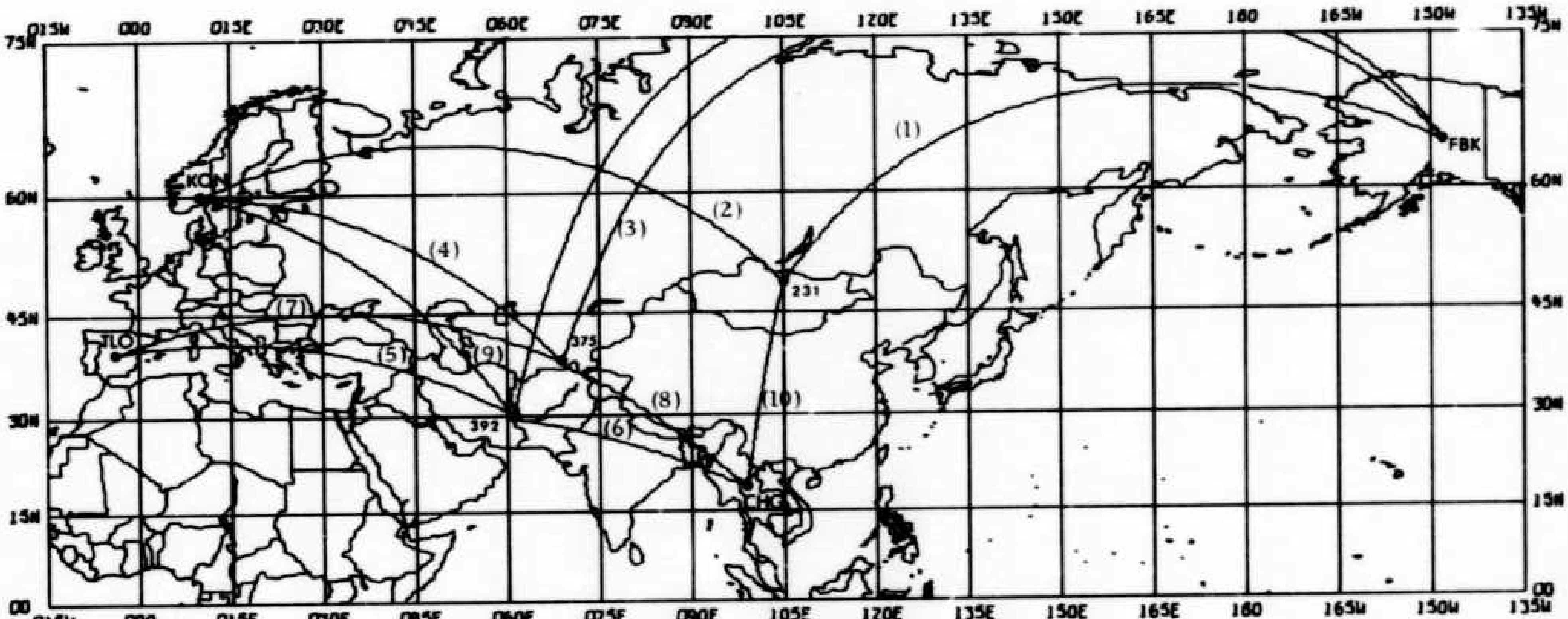
EVENT AND STATION PARAMETERS

EVENT PARAMETERS

Event Number	Date	Area	Lat.	Long.	O. T.	m_b	h
231	2/26/72	USSR-Mongolia Border	50.6N	97.1 E	23:31:04	5.2	-
375	3/17/72	Tadzhik, USSR	40.1N	70.0 E	09:17:11	5.2	29
392	3/20/72	S. W. Afganistan	30.0N	60.0 E	20:08:31	3.4	-

VLPE STATION PARAMETERS AND EPICENTRAL DISTANCES

VLPE Station Parameters				Distance in Degrees		
Station	Designator	Lat.	Long.	231	375	392
Chiang Mai, Thailand	CHG	18.79 N	98.98 E	30.4	32.1	36.9
Fairbanks, Alaska	FBK	64.90 N	148.01 W	55.5	72.5	81.8
Toledo, Spain	TLO	39.86 N	4.02W	-	54.7	52.6
Kongsberg, Norway	KON	59.65 N	9.59 E	48.3	42.3	44.9



MILLER MODIFIED MERCATOR PROJECTION
MAP SCALE: 0.600 IN./ 15 DEG. LONGITUDE

FIGURE II-1

STATION AND EVENT LOCATIONS

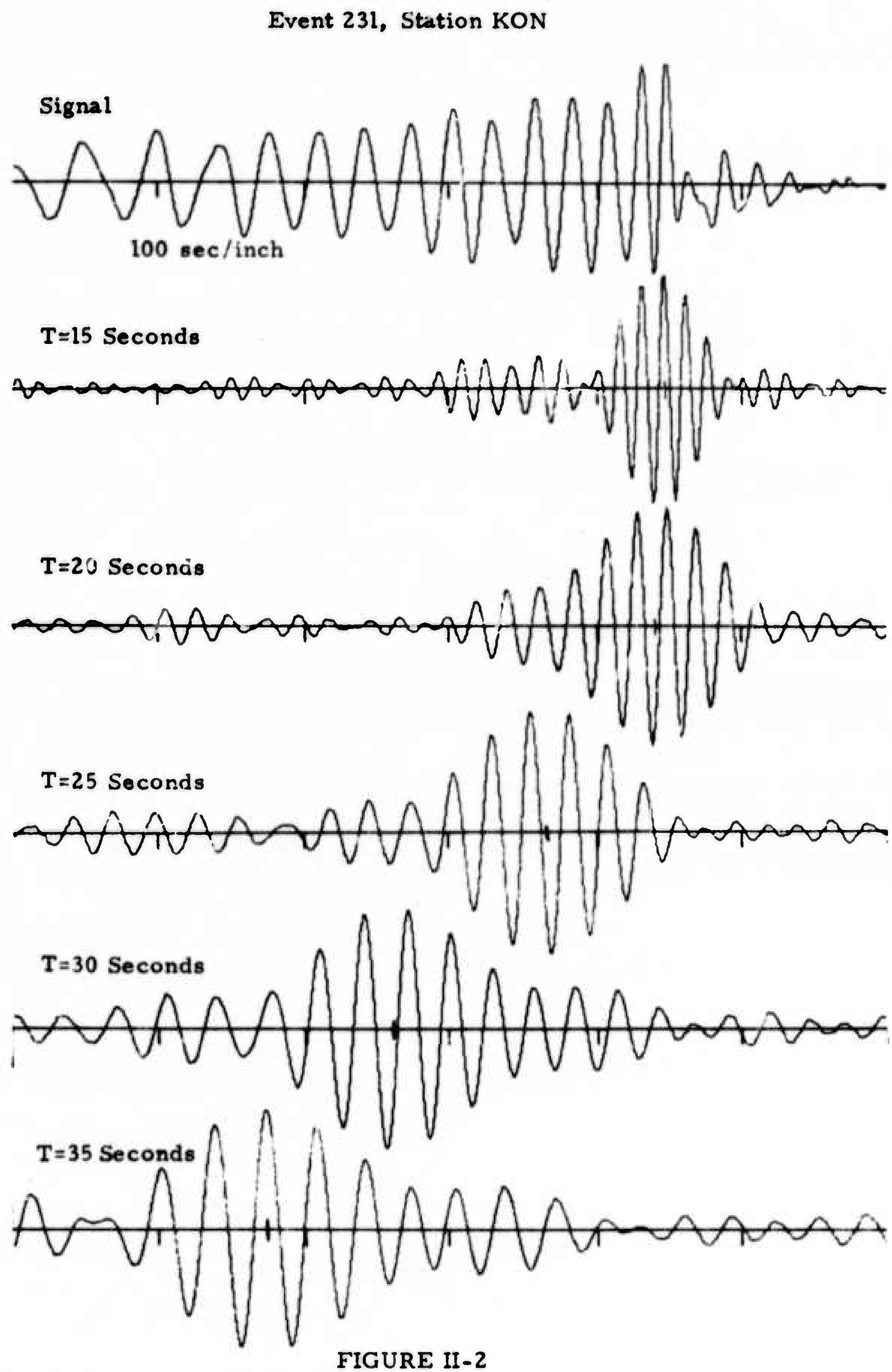


FIGURE II-2

TYPICAL OUTPUTS FROM NARROW BAND FILTERING

We believe the determination of group velocities and spectra by this method to be intrinsically more reliable than other methods for the following reasons:

- It is well known that lateral variations along the propagating path can cause deviations from the expected direction of the various group arrivals of surface waves (Evernden, 1953, Alexander, 1963, Glover and Alexander, 1969, and Newton, 1973). These effects may be termed as multipathing.
- Fourier spectral estimations of the total signal time series may not be valid for the fundamental mode since some earthquakes do excite significant higher mode energy.
- Bursts of noise in the signal gate can be better discerned and discarded.

Thus, some of the effects of noise, multipathing and the presence of higher modes can be minimized with the proper use of narrow band filtering in the determination of fundamental Rayleigh wave group velocities and spectra.

SECTION III
RESULTS

A. GROUP VELOCITIES

Fundamental Rayleigh wave group velocities for ten Eurasian paths are shown in Figure III-1. In the determination of these group velocities, we did not correct for either the source phase or instrumental phase response. However, the epicentral distances are large and the VLPE instrument amplitude response is nearly flat between periods of 25 to 45 seconds. Thus, the errors due to either source or instrument phase terms should be insignificant.

The observed group velocities are indicated by the various defined symbols on the graphs. Included for comparison (solid line) is the group velocity curve determined from McEvilly's (1964) model for the mid-continental United States crust and upper mantle structure. This model varies only slightly from Brune and Dormans (1963) Canadian Shield (CANSD) model (Table III-1).

Events 231 and 375 lie on the northern portions of massive fold systems and 392 is located on the southern side of the Alpine-Himalayan fold system. Paths 1 through 4 from events 231 and 375 to FBK and KON, Figure II-1, cross the Siberian, Northeastern Siberian, Western Siberian and Russian platforms. The general tectonic regions have been defined by Rodriguez (1969). Further, paths 5 and 6, from event 392 to TLC and CHG cross Iran, Greece, Turkey, and the Mediterranean region, and the northern part of India all of which are essentially platform regions. The observed group velocity curves for the first six paths crossing platform regions compare closely to that of McEvilly's mid-continental United States and

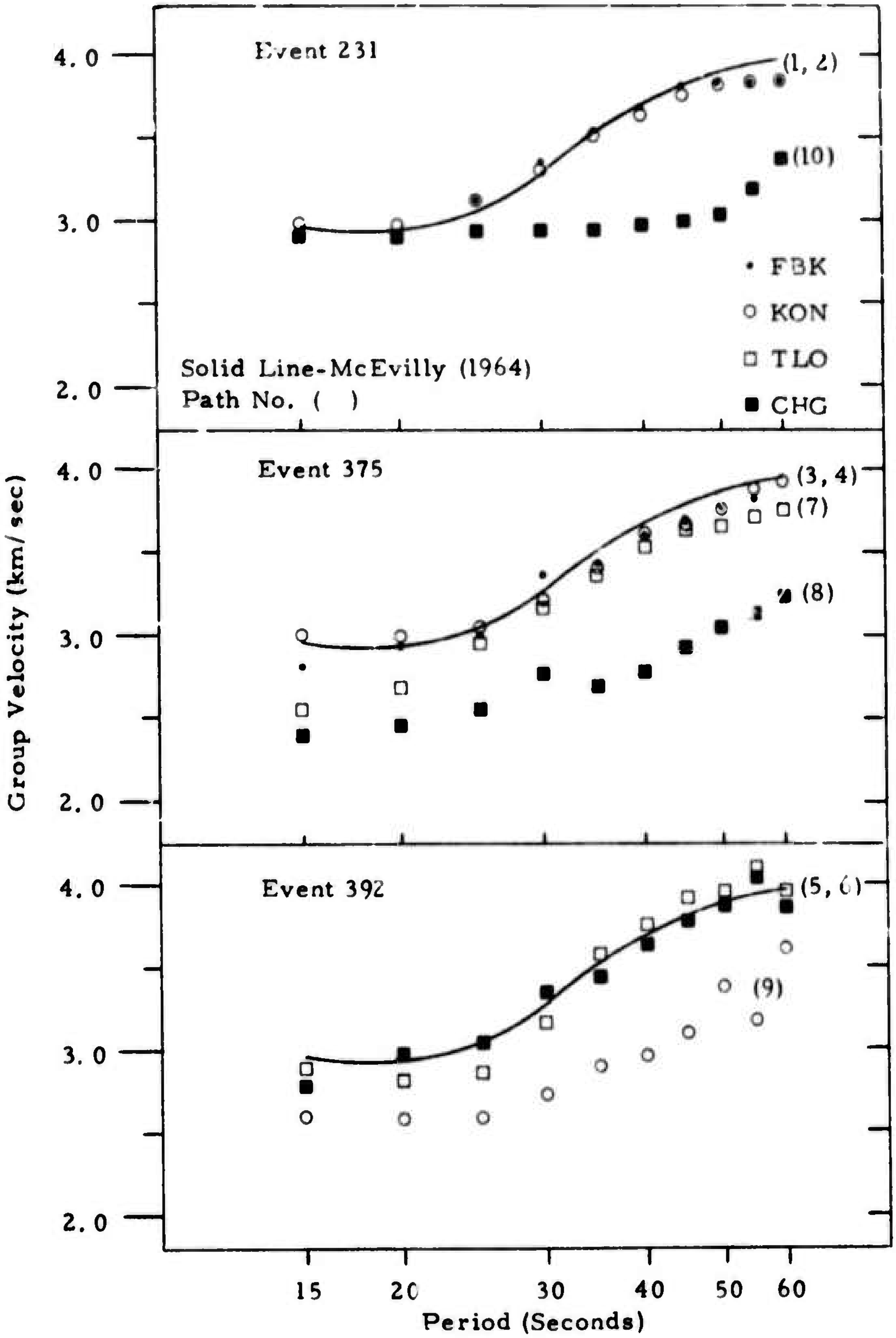


FIGURE III-1

OBSERVED RAYLEIGH WAVE GROUP VELOCITIES
FOR 10 EURASIAN PATHS

TABLE III-1

COMPARISON OF CANSD AND MCEVILLY'S EARTH MODELS FOR THE CENTRAL UNITED STATES

CANSD (1963)				MCEVILLY (1964)			
H	α	β	ρ	H	α	β	ρ
6.0	5.64	3.47	2.70	11.0	6.1	3.50	2.70
10.5	6.15	3.64	2.80	9.0	6.4	3.68	2.90
18.7	6.60	3.85	2.85	18.0	6.7	3.94	2.90
80.0	8.10	4.72	3.30	24.0	8.15	4.75	3.30
100.0	8.2	4.54	3.44	40.0	8.2	4.61	3.30
100.0	8.3	4.51	3.53	18.0	8.2	4.45	3.30
80.0	8.7	4.76	3.60	-	8.7	4.80	3.60

H = Thickness (km), α = Compressional Wave Velocity,
β = Shear Wave Velocity, ρ = Density

CANSD dispersion curve. Other observational evidence by Santo and Sato (1966) verify our group velocity determinations for platform regions in Eurasia.

Paths 7 and 9, Event 375 to TLO and Event 392 to KON, are considerably more complex in that they include the Caspain and Black Sea, crustal structure and portions of the Alpine-Himalayan fold system. For these paths we observe lower average crustal velocities than for the platform regions (see Figure III-1).

Path 8 (Event 375 to CHG) is parallel to and in the Alpine-Himalayan fold system and we observe an overall lower group velocity curve which is indicative of a substantial increase in crustal thickness over the travel path as compared to the platform regions.

Path 10, event 231 to CHG, crosses the Central Asian, Central China fold systems and a portion of the Tibet platform. We were unable to determine valid group velocities for this path and from inspection of the signal time series and narrow band output in Figure III-2 it is clearly evident that multipathing does occur. The group velocities shown in Figure III-1 were determined by averaging the time of one or more of the wave packets from the narrow band filtering. The results indicate low group velocities over a large period band and imply large crustal thicknesses of relatively constant velocity. The multipathing is more likely due to the extremely complicated path which is comprised of the two major fold systems and the Tibet platform.

B. GROUP SPECTRA

Figures III-3, 4 and 5 show the group spectra by event (231, 375, and 392), corrected for instrument response, geometrical spreading, and effective Q. All spectra were corrected according to Tryggvason's (1965) effective energy dissipation (k_e) curves shown in Figure III-6.

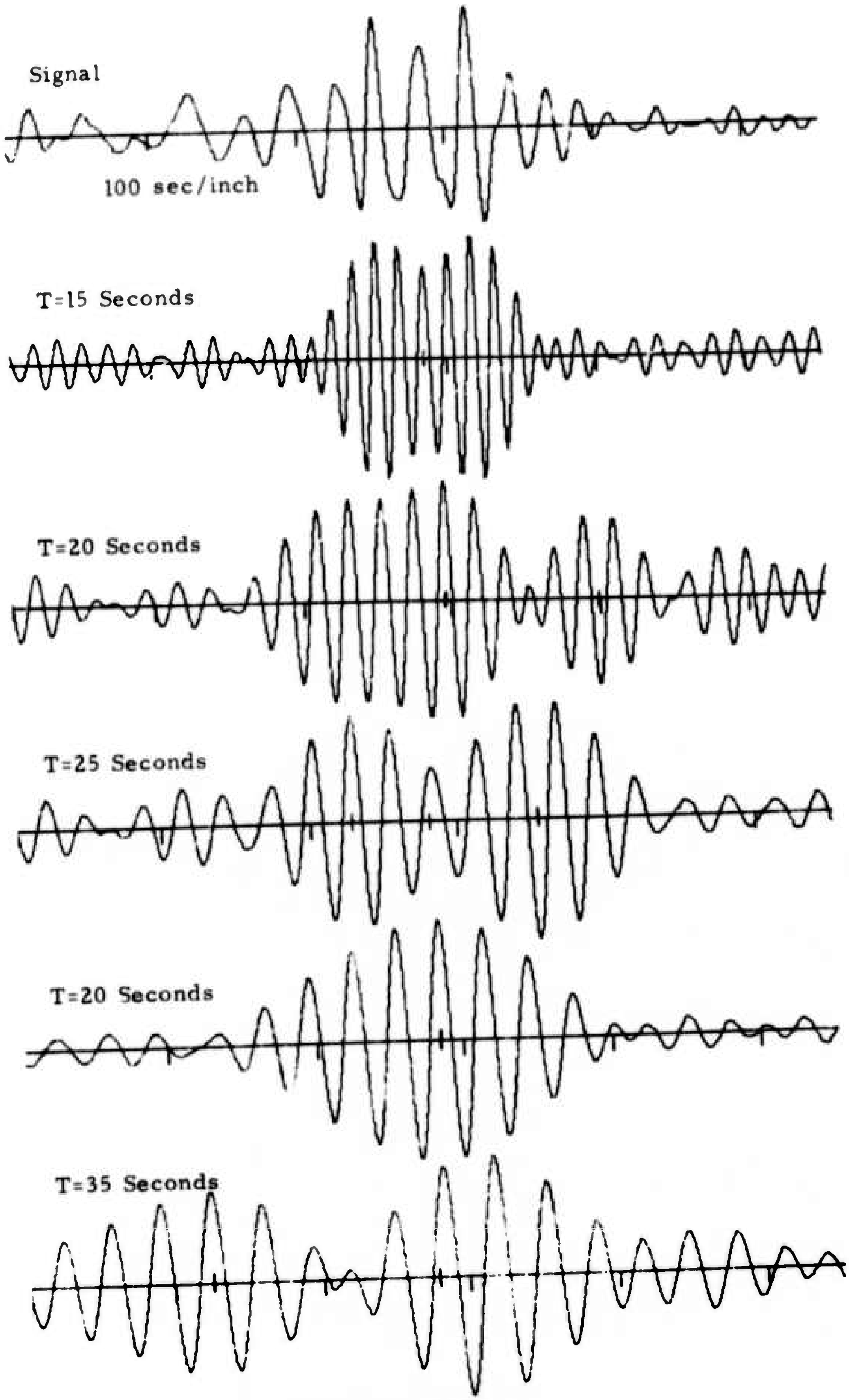


FIGURE III-2

OUTPUT FROM NARROW BAND FILTERING
OF THE CHG RECORD OF EVENT 392

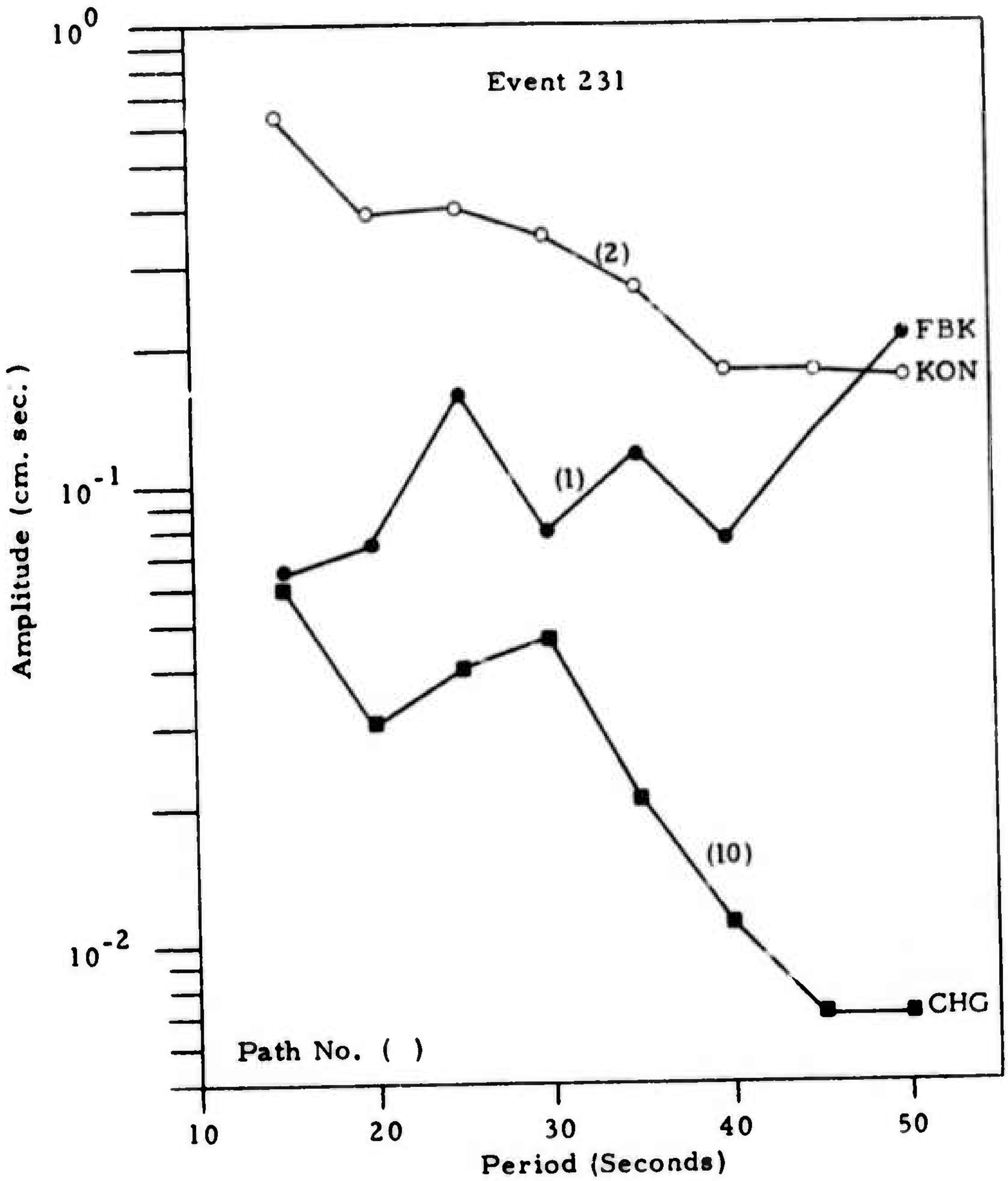


FIGURE III-3

EVENT SOURCE SPECTRA FOR EVENT 231

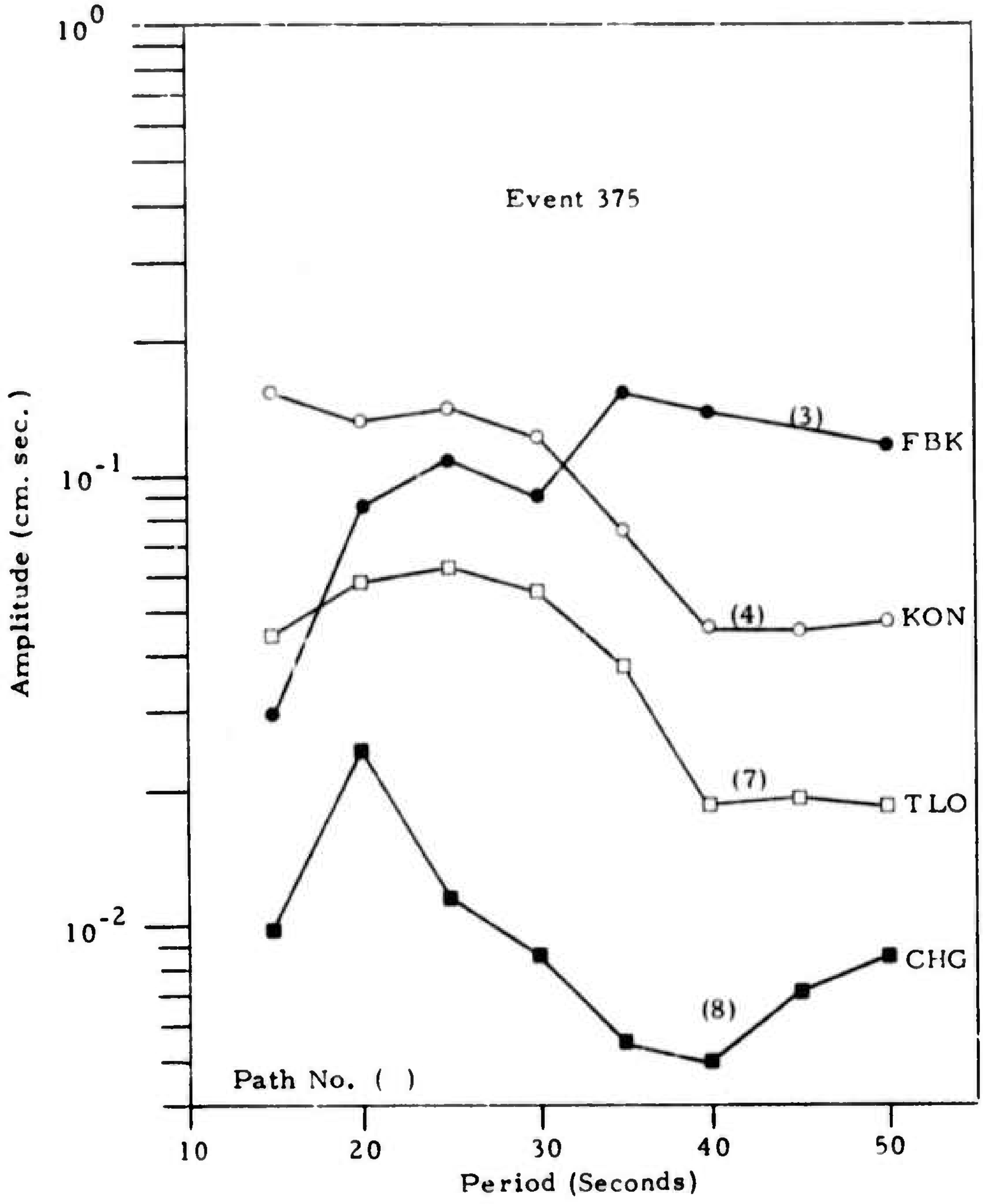


FIGURE III-4

GROUP SOURCE SPECTRA FOR EVENT 375

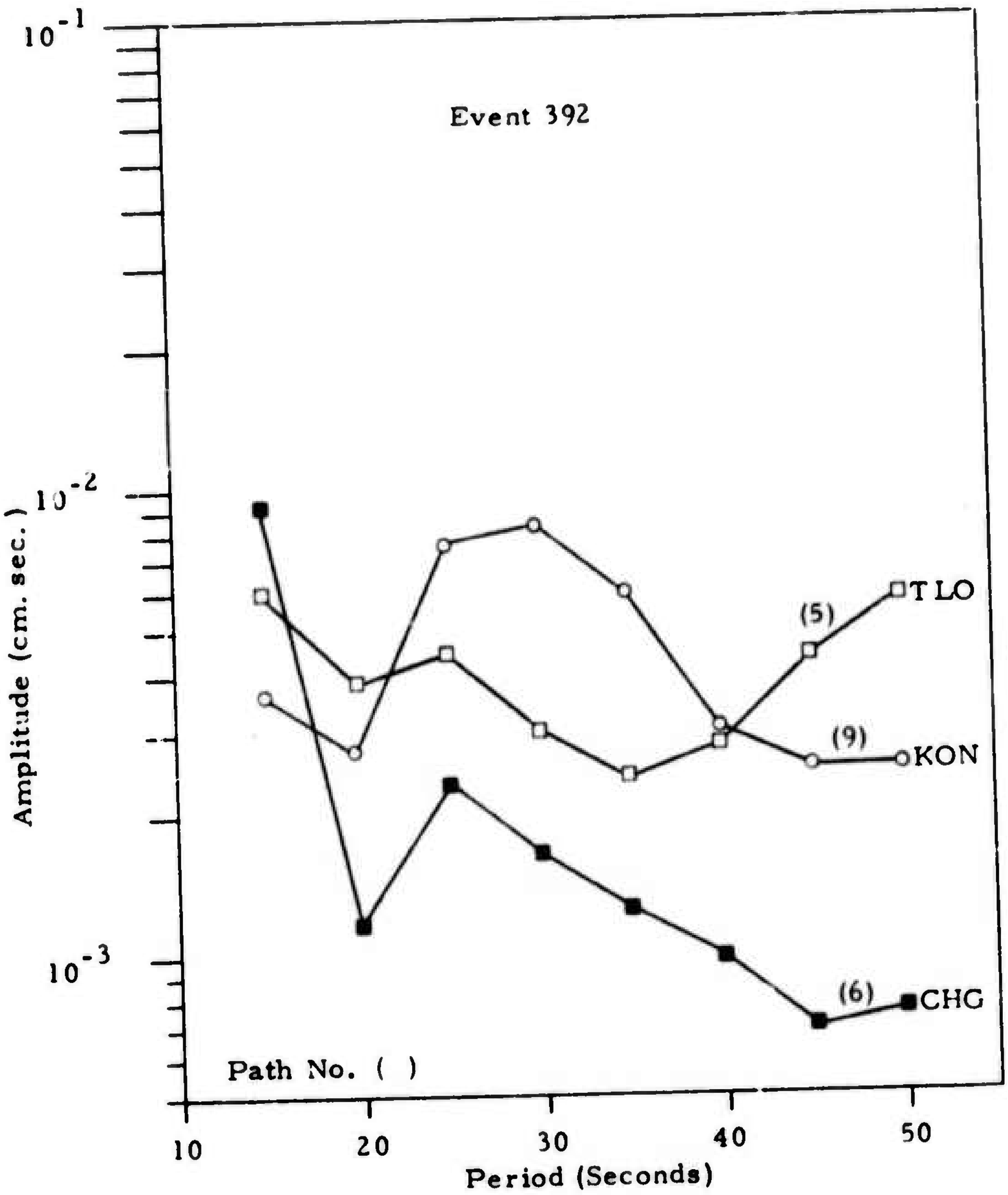


FIGURE III-5

GROUP SOURCE SPECTRA FOR EVENT 392

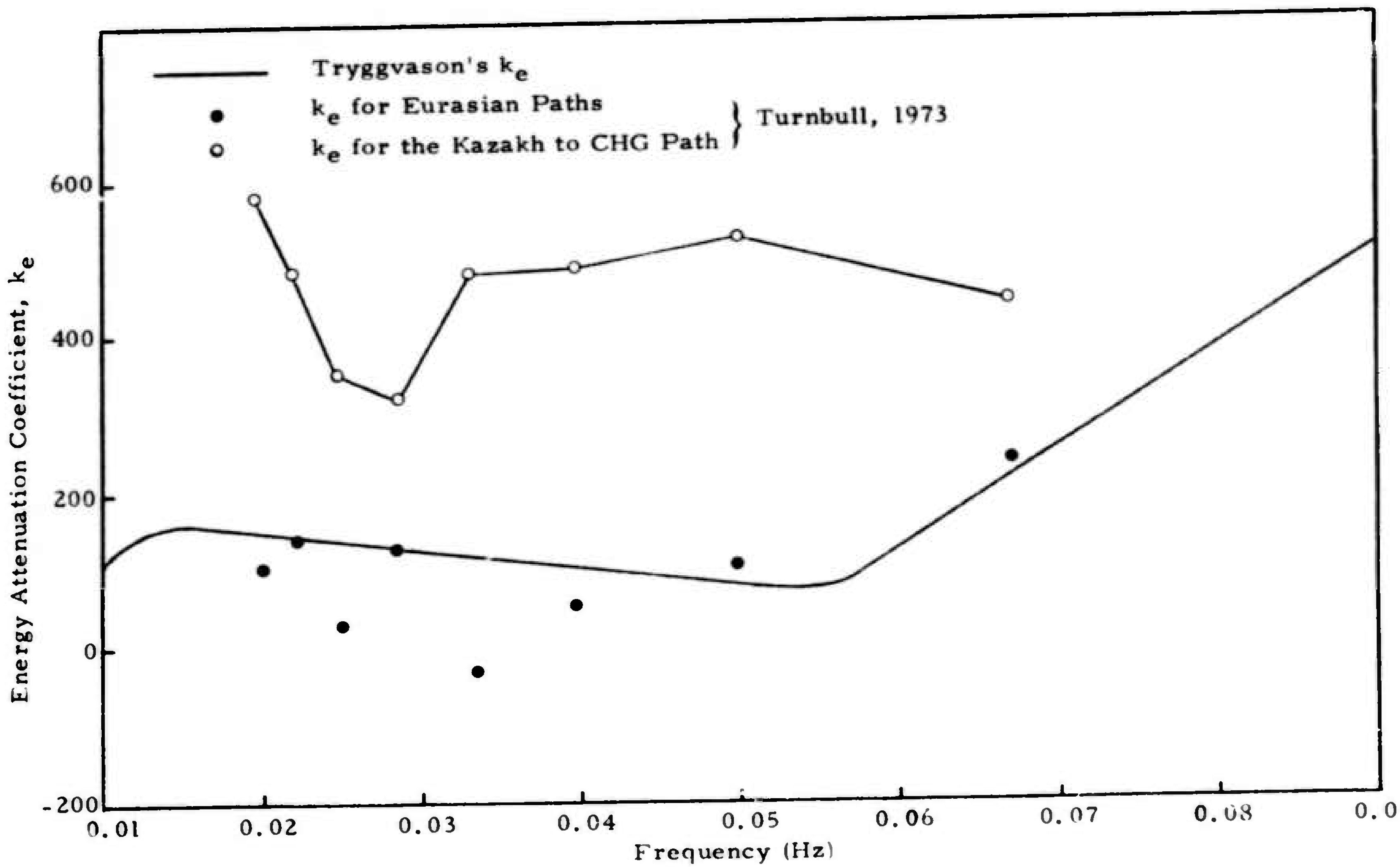


FIGURE III-6

ENERGY ATTENUATION COEFFICIENT, k_e, FOR EURASIAN PATHS

This curve was derived from WWSSN station records of four presumed Novaya Zemlya explosions and several natural earthquakes. Turnbull (1973) also determined in a similar manner the effective energy dissipation from VLPE records of two presumed Eastern Kazakh explosions. His results are shown with the open circles and are in close agreement with Tryggvason's results. Further, Turnbull calculated the effective energy dissipation for the path from Eastern Kazakh to CHG (solid dots). This path crosses the Alpine-Himalayan Fold System. The data in this figure provides the basis of the discussion for our spectral estimations.

We can make the following general comments concerning the source amplitude spectra shown in Figure 3, 4, and 5.

- The spectral amplitudes for all events with the exception of the look direction represented by CHG, are overlapping and relatively close in value to each other. These differences can be attributed to the event radiation patterns and to the lack of precise effective energy dissipation (k_e) factors for each path.

- The source spectra for the look direction represented by CHG, as previously stated, was corrected using Tryggvason's k_e. These amplitudes are significantly lower than those determined from the other stations, especially at the longer periods. Correcting these spectra with the k_e determined by Turnbull (Figure 6) will result in increasing the amplitudes by a factor of about 2. The shapes of the spectra will not change appreciably. The amplitude levels for path 6 now become comparable to the others. However, for paths 8 and 10, only the amplitudes at short periods (15 to 30 second periods) become comparable while for the longer periods the amplitudes remain low.

SECTION IV

DISCUSSION OF RESULTS

The group velocities measured over the range of periods from 15 to 60 seconds are sampling the crust and upper mantle structure to depths up to 300 kilometers. Thus, differences in the observed group velocity curves relative to CANSD or McEvilly's reference group velocity curve can be explained by variations in thicknesses and elastic parameters of the crust and upper mantle. Figure 1 shows typical cross sections of the crust and upper mantle for the appropriate paths used in this study (Rodriguez, 1969).

The observed group velocities for paths 1 through 6 (paths through Platform regions) show slightly lower velocities at periods of 50 to 60 seconds than McEvilly. This suggests that the low velocity zone in the upper mantle is thicker than the indicated 58 kilometers by McEvilly. It is probable that the thickness of 200 kilometers shown for the CANSD model would have provided more appropriate velocity values for these longer periods.

The observed group velocities for path 7, which crossed the Caspian and Black Sea regions reflects the thickening of the low velocity surfacial layer, thinning of the crust and lower moho velocity. Here, the short period velocities are significantly lower, the slope for the intermediate periods is comparable, and the overall velocity curve is lower than that observed for the platform regions. The cross section in Figure IV-1 for the Caspian and Black Sea clearly supports these general observations.

Path 9 is a complicated path which crosses the Alpine-Himalayan fold system, Caspian Sea region and the Russian platform. We observed significantly overall lower group velocities but little or no unusual variations in amplitude levels. Since the observed group velocities are averages of the structures traversed, we can only suggest that the Alpine-

Himalayan fold system portion of the path was small in distance compared to the rest of the path. This caused lower group velocities but had little effect on the effective attenuation of the Rayleigh wave.

Paths 8 and 10 are extremely complex in that path 8 traverses the Alpine-Himalayan fold system and path 10 crosses the Central Asian, Central China fold systems and a portion of the Tibet platform. The fold systems result from the collision of continents according to the theory of plate tectonics (Metz and Hammond, 1974). The Himalayas are thought to have formed when the Indian subcontinent collided with the Eurasian continent. Little is known about mountain building caused by continental collisions since vertical motions are almost as rapid as horizontal motions.

Thus, the cross section shown for the Alpine-Himalayan and for the other fold systems (Figure IV-1) is an over simplification of the true structure. However, it does provide an explanation for the observed low group velocities and amplitudes by indicating large crustal thicknesses totaling about 75 kilometers.

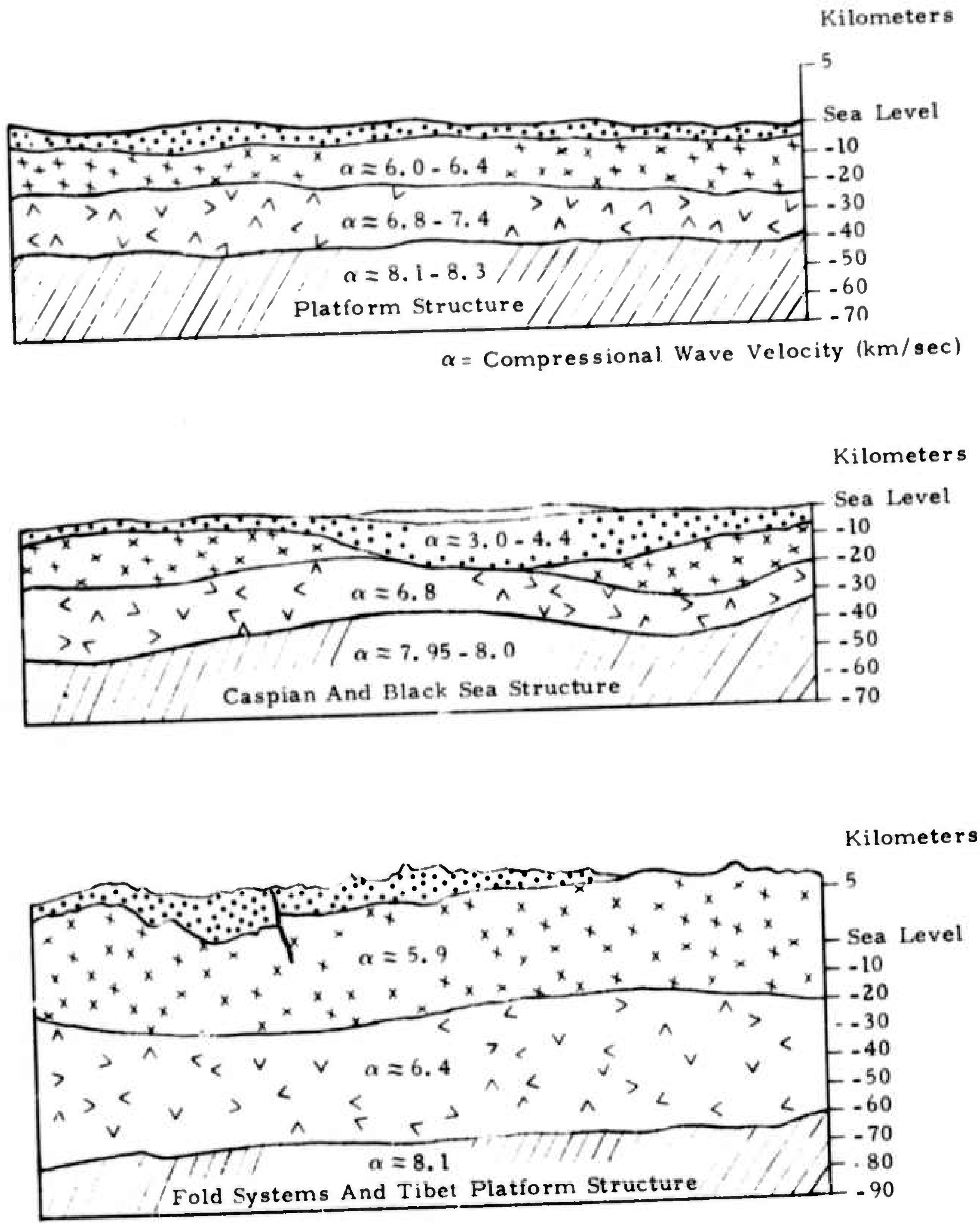


FIGURE IV-1

TYPICAL CROSS SECTIONS FOR PLATFORM, CASPIAN AND BLACK SEA, AND FOLD SYSTEMS

SECTION V

SUMMARY

Eurasia is comprised of vast platform structures. The observed Rayleigh wave group velocities indicate that the structure of the crust and upper mantle for these regions is similar to that of the Central United States. Various authors have written that all continents have essentially the same crust and upper mantle structures. Thus, these results were as expected.

However, for paths encompassing fold systems such as the Alpine-Himalayan, Central China, and Central Asian, we found a significant decrease in the Rayleigh wave group velocities and amplitudes, indicating high effective attenuation properties. Further, for path 10, multipathing is evident.

SECTION VI

ACKNOWLEDGMENTS

The author wishes to thank T. W. Harley and L. S. Turnbull for their helpful discussions and critical reading of this paper. I am also grateful to J. S. Shaub for his capable assistance in processing and reduction of the data.

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